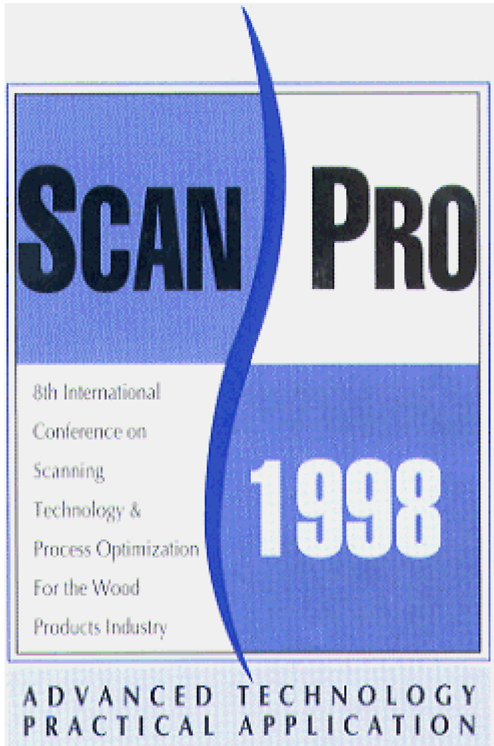

What's Ahead in Automated Lumber Grading

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ABSTRACT

This paper discusses how present scanning technologies are being applied to automatic lumber grading. The presentation focuses on 1) what sensing and scanning devices are needed to measure information for accurate grading feature detection, 2) the hardware and software needed to efficiently process this information, and 3) specific issues related to softwood lumber grading and hardwood lumber grading. Practical experiences will be shared as to the advantages and limitations of automatic lumber grading technologies. Guidance will be provided on how to justify the purchase of these systems, as they become commercially available and proven technologies.

INTRODUCTION

Within the next two years, the lumber manufacturing industry will see some of the first installations of automatic lumber grading systems. These systems will involve complicated mechanisms including cameras, lights, lasers, x-rays, computers, electronics and other devices necessary to identify lumber grading features. Large and sophisticated computer software will be needed to process the volume of information generated by the scanning hardware. The resulting "digital map" of lumber grading features outputted by the software will be used to automatically sort and grade lumber according to standard grading rules (e.g. WWPA, SPIB, NHLA). However, this data can also provide a potential wealth of information to dramatically reduce costs and increase value recovery by creating a more intelligent, more adaptable manufacturing system.

Justification of automatic lumber grading systems through labor savings alone is inappropriate for many lumber manufacturers. The grading system will most likely still require an operator to oversee and sometimes override its operation. The primary cost savings from the system will be realized by producing a more uniform and consistently graded product and by producing a higher value product through optimum lumber remanufacturing. Other cost savings can be realized by reducing manual and repetitive labor requirements, and streamlining the mill through a more controlled and efficient lumber grading/sorting process. New value added opportunities can be realized with the ability to switch to any number of standard, customized or proprietary lumber grades as needed "on the fly". New marketing opportunities can also be realized by providing a precise description of the lumber on a disk or on the Internet to customers.

This paper will describe how present scanning technologies are being applied to automatic lumber grading. We will focus on: what scanning devices are needed; the hardware and software needed; and specific issues related to softwood and hardwood lumber grading. Practical experiences will be shared as to the advantages and limitations of automatic lumber grading technologies.

MULTIPLE SENSOR LUMBER SCANNING SYSTEM

To automate lumber grading, the industry now recognizes that a multiple sensor approach to scanning must be used to get the required accuracy, consistency, and repeatability. There are three main categories into which lumber-grading features may be classified. These are: 1) visual surface features (e.g. knots, holes, splits, decay, discoloration, slope-of-grain), 2) geometry features (e.g., 3-D shape, warp, wane, thickness variations), and 3) internal features (e.g., internal voids, internal knots, decay, compression wood). Most of these features are treated as defects in lumber grading and need to be removed in manufacturing processes. Table 1 shows common features that are important in determining lumber grade and the common sensing modality used to automatically detect those features.

Recognizing that not all grading features can be detected with one single sensing mechanism, current R&D efforts are focussing on developing lumber grading systems that combine 2 or more of these sensing modalities. Many years of industrial experience with some sensors such as black and white or color cameras have resulted in fast, robust, and inexpensive sensing systems. Some of the more recently introduced sensing technologies such as x-rays, microwave, and ultrasound are typically developed first for an application (e.g., medical industry) where speed, cost, and harsh environment are not critical factors. Several years of experience with such sensing systems will be needed before they are reliable and robust enough for lumber manufacturing and grading applications.

Table 1
Hardwood grading features and the sensors required to automatically detect those features

Feature	Sensor(s) Required for Automatic Detection
Thickness, Crook, Bow, Cup, Twist	Mechanical, Laser Profiler
Wane, Profile/Shape, Voids/Holes, Planer Skip	Laser Profiler, Black & White Camera
Pitch/Gum Pockets, Mineral Streak, Surface Knots, Pith	Black & White or Color Camera, X-ray
Wood Color, Stains, Discolorations	Color Camera, Spectrometer
Internal Knots, Decay, Compression Wood	X-ray, NMR, Microwave, Ultrasound
Honeycomb, Splits, Internal Voids	X-ray, Ultrasound
Slope of Grain	Laser Reflectance, Capacitance

HARDWARE AND SOFTWARE

The overall conceptualization of an automatic lumber grading system is shown in Figure 1. A precision lumber handling system moves the lumber through a scanning head at the speeds necessary for production. The scanning head contains all of the cameras, lights, lasers, and other scanning devices necessary to identify lumber grading features. The exact configuration of the scanning head depends on the species/size of lumber, the production speeds, the resolution, and precision required. The image processing computer processes the images collected from the scanning head to locate and identify all lumber grading features. The resulting "digital map" of lumber grading features can then be used to grade the lumber according to the required grading rule (e.g. SPIB, WWPA, NHLA, or custom). The resulting lumber grade can be used to automatically control a bar-coding or printing device to stamp the lumber grade on the piece of lumber. The digital map can also be used to determine if the lumber can be re-manufactured into a higher-value product and automatically direct a numerically controlled sawing system to produce higher value lumber.

The lumber grading system shown in Figure 1 assumes that a mill operation can handle lumber grading in the linear direction. Transverse scanning systems can also be developed for those operations that prefer handling lumber grading in the transverse direction. Transverse scanning systems would have multiple scanning heads (e.g. at every 2-ft. intervals). While transverse-scanning systems offers the advantage of faster throughput and requiring fewer material handling changes in some mills, such scanning system would be much more sophisticated and expensive. Also, the probability of a particular scanning head failure would be higher making it more difficult to debug and maintain. The general rule-of-thumb for such a sophisticated technology is: “the simpler, the better”.

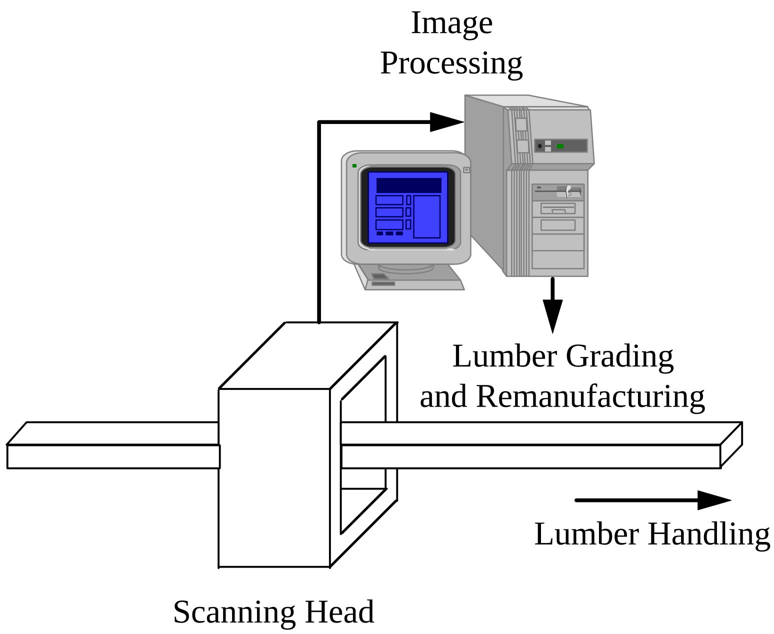


Figure 1. A lumber grading system will include a material handling system that moves lumber linearly through a scanning head, image collection hardware, and image processing software.

Real-Time Image Collection Hardware

Softwood and hardwood lumber grading rules require the identification and location of sometimes rather small defects. Therefore, image-processing systems must be able to collect and process very large images with relatively fine resolutions to accurately locate and identify these defects. In image processing systems, each picture element size (pixel) must be at least half the size of the smallest feature that must be resolved. For example, if ¼” diameter knots must resolved, the maximum pixel size must be 1/8” x 1/8” for reliable detection. While a good majority of lumber grading defects can be adequately detected with image resolutions of 1/8” in resolution, there are some critical grading defects that require much finer resolutions to ensure their detection (e.g. pin knots, worm holes, splits, checks, and planer skip).

With multiple-sensor scanning systems, each additional channel of sensor information adds to the magnitude and complexity of the image data that must be processed. Since grading applications need to know the exact location of a defect in two-dimensional space from a known reference point, each channel of information must be precisely registered with this reference point. In lumber strength grading applications, some three-dimensional information is needed to calculate knot displacement. This implies that corresponding channels of image data from all 4 sides of a scanned board also need to be registered with the same reference point. Finally, the image resolution of each channel must be identical or multiples of each other to avoid computationally complex image transformation functions. All of these channels of high-resolution registered image data from different faces of a board surface require a sophisticated hardware and software system that can collect and handle the data in real time.

The image data collection hardware must collect and synchronize images from all sensors and perform low-level functions on these images such as image registration, shade correction, board boundary detection, and image histogram generation in real-time. The real-time image data must also be transferred to computer memory using a high-capacity direct memory interface. Through this spcialized hardware configuration, real-time processing of the large amounts of image data (as fast as it is collected) is possible. With the latest in digital electronics supporting the industry standard PCI computer interface (which can now handle over 50 Mbytes of data per second), computer hardware is no longer the bottleneck in real-time collection of image data. Rather, the speed at which sensing mechanisms can physically measure data is now the limiting factor for the speed and resolution at which these systems can operate.

Real-Time Image-Processing Software

There are a couple of challenges in developing image-processing software for automatic lumber grading. The first challenge is developing a robust software system that can intelligently handle the immense variability in the nature and appearance of wood to accurately identify the many possible grading features present. Examples of this variability and the challenges it creates will be discussed in the next section. The second challenge is designing and ordering the software system so that it can be performed in real-time. Even though the benchmark processing speed for PC-based computer systems is increasing every month, the level of sophistication needed in the software is such that multi-processors will be needed to address certain applications in real-time. Current software technologies are now such that it is relatively easy to upgrade to a faster computer system. However, remember that a faster computer will not necessarily solve processing speed problems. Rather, the additional capability means that data will be massaged even further to get that extra piece of information that wasn't possible before.

When grading lumber, relatively few examples of a particular grading defect have to be shown to human graders before they learn how to accurately identify them. With a computer, however, many examples of a particular feature are required before the complete variability of that feature is represented. For example, with an explanation of what knots are and a few examples, a human can quickly recognize future occurrences of knots with relative ease even if the color and shape of knots are significantly different than the first examples. Conversely, the broad spectrum of shapes, sizes, colors, etc. need to be represented in the computer before automatic recognition of knots becomes robust. Currently, this computer training effort can be a time-consuming process and software systems must be designed with intuitive and easy-to-use interfaces to help speed the training process.

LUMBER GRADING ISSUES

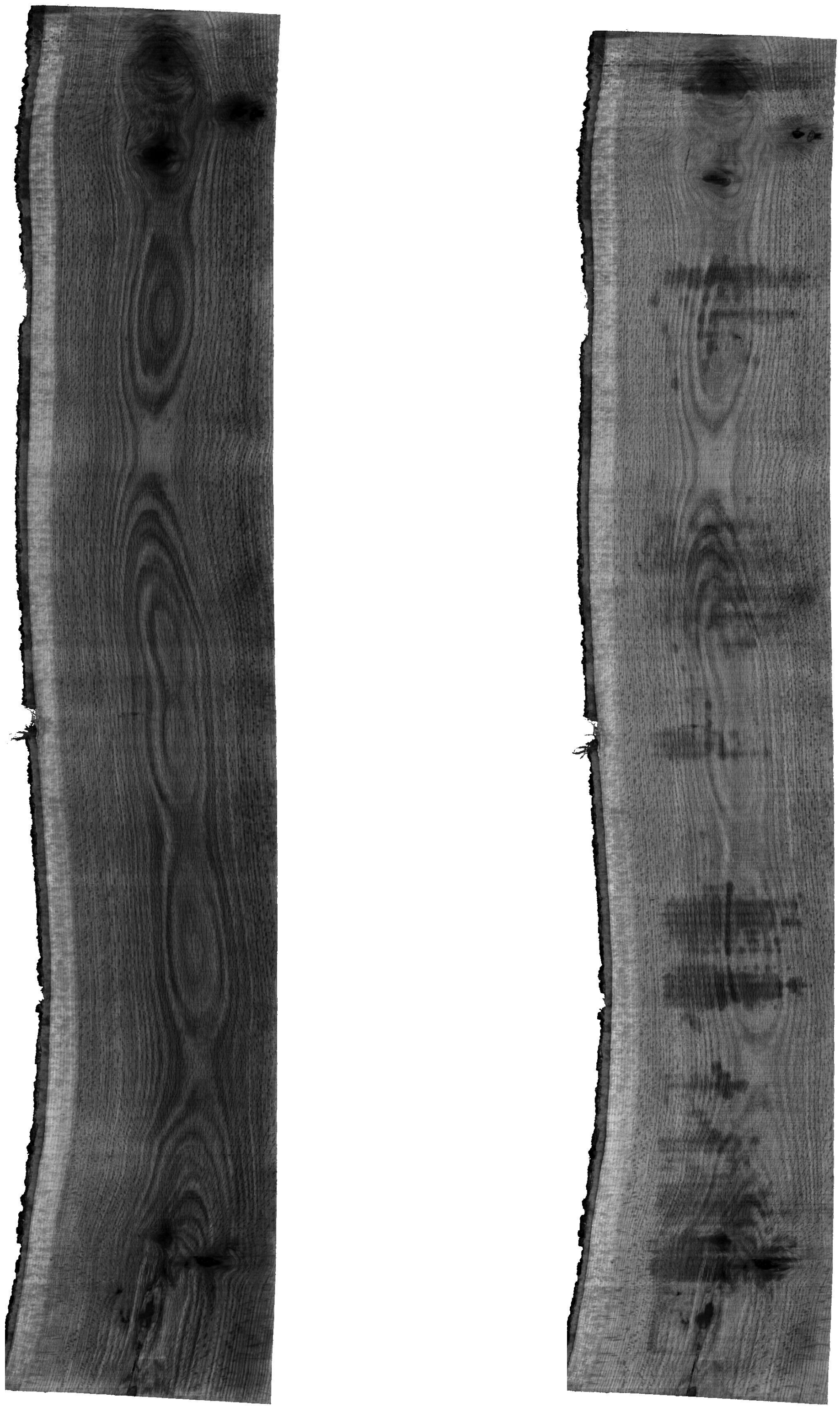
Virginia Tech and the Southern Research Station of the USDA Forest Service have jointly developed and refined a multiple-sensor lumber scanning prototype (Conners, et al. 1997; Kline, et al. 1997) to demonstrate and test applicable scanning technologies. One of the objectives of the R&D effort is to create an extensive lumber image data-base. From this database, standards are being developed as to what information is contributed by different sensing technologies in the recognition of grading features for various commercial lumber species. From these standards, image-processing algorithms are being developed to better recognize a broader spectrum of lumber grading feature types for the various species. We will discuss some of our findings to date and discuss what implications they have in the development of automatic lumber grading systems.

Effect of Moisture Content in Wood

Moisture Content in wood has a marked impact on the variation in information that is collected from the various sensing elements. This variation is also dependent on the species of wood. Figure 2 shows images of southern yellow pine (SYP) and red oak lumber in both the green and dry condition. In dry SYP, heartwood is significantly darker in when lumber is dried. Overall, however, there is very little change in the brightness in sapwood between the green and dry condition. The opposite is observed for red oak where, the heartwood is darker in the green condition. Additionally as the surface of red oak dries, the overall brightness for both heart and sap significantly increases. The overall variability in brightness changes little for SYP where it is dramatically reduced for red oak. When looking at color, there is very little change in color for SYP between green and dry. As the surface dries in red oak, its color becomes less red with a touch of green tint added. All of these moisture content changes in wood as illustrated in Figure 2 can have a profound effect in the performance of light-intensity-based feature recognition algorithms. As such, installation of machine grading systems must be such that moisture content and surface condition be fairly uniform during lumber grading.

Typically, grading hardwood lumber on the green chain can pose problems as shown in the case of Figure 3. As the surface of red oak lumber dries, some remaining darker wet spots can confuse recognition software if it is not trained for such possibilities.

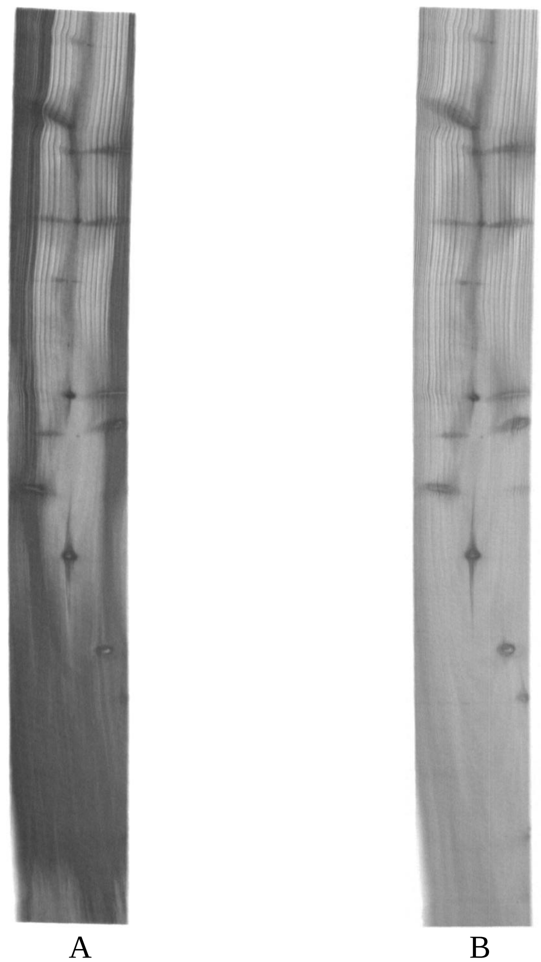
Figure 1. Images for (A) green and (B) dry southern yellow pine and (C) green and (D) dry red oak



(A) (B)

Figure 3. Red oak images of the same board where (A) the surface is completely green and (B) the surface is partially dry.

Figures 2 and 3 illustrate brightness differences in wood for various moisture contents. Wood density differences can also be markedly affected by moisture content. Figure 4 shows the x-ray images for the same SYP board for both the green and dry condition. The heartwood in SYP tends to hold significantly less moisture than sapwood. This can cause extreme density variations in wet wood. In figure 4, some of the knots are totally hidden in the wet sapwood. Such unpredictable conditions in wet wood can create challenges when developing feature recognition software for x-ray images of green wood. For red oak, in general, both heartwood and sapwood both tend to hold the same amount of water in the green condition. However, such observations in moisture content and wood density depend on not only on species, but also growth condition and the time a log remains in the log yard.



A B

Figure 4. X-ray images of the same southern yellow pine board in the (A) green and (B) dry condition

Variability in Wood

There are many factors that cause variability in wood, not only between species, but also within a particular species. In addition to environmental factors such as moisture content (discussed above) and surface condition (soil marks, roughness, color change due to UV light, etc.) there is always the natural variability in wood. For example, the color, density, and shape of a knot are all extremely variable. This variability causes overlap with other grading features and can cause confusion in identification. Understanding this variability in relation to other measurable quantities is a key to improving the performance of lumber grading systems. For example, if the brightness of clearwood is high, then the brightness of grading features such as knots will tend to be greater. A successful lumber grading system depends on a thorough understanding of this variability and will incorporate algorithms that can handle and adapt to this variability. As such, these algorithms must include a well designed set of tools that allow production level lumber image capture, image library creation, ground truthing (i.e. what are the true grading features present), semi-automatic training, and regression testing. Some of the standards being developed with Virginia Tech's lumber scanning are aimed at assisting in this algorithm development effort.

"Man-in-the-Loop" Concept

Current claims are made that promote the concept of totally automatic lumber grading. Such an approach would set such a relatively new technology up for failure. End-users of this new technology must understand that the first installations of these systems will be semi-automatic. In a semi-automatic system, a human operator must be able to override or augment the computer system's results. While, such a semi-automatic system can help the user achieve an overall productivity improvement, user-overrides can be saved as examples of what to do better as future training data. Furthermore, keeping a human operator "in-the-loop" will help dramatically in the initial acceptance and confidence in the system.

System Support and Maintenance

System support and maintenance will be another feature that must be carefully considered in machine lumber grading systems. A minimum support system would include such features as:

1. Dial-in connection for system troubleshooting, result downloads, and system upgrades.
2. Telephone hot-line support for the "system administrator".
3. On-site support options made available within response time constraints.
4. Ability to bring down system and not completely cripple mill production.
5. Periodic maintenance schedule.
6. Periodic system diagnostic tests.
7. Generation of reports to illustrate payback specific to the objectives of the mill.

CONCLUSION

Machine lumber grading systems will be making their debut in the next several years. The primary cost savings from such a system will be realized by producing a more uniform and consistently graded product and by producing a higher value product through optimum lumber remanufacturing. Technology is now available to create such systems. However, adapting this technology for lumber grading applications will take several years. Successfully delivering such grading systems to the end user will depend upon a good understanding by equipment manufacturers, mill managers, and operators alike on the level of sophistication of technology and the associated learning curve that is needed to handle an extremely variable material called “wood”.

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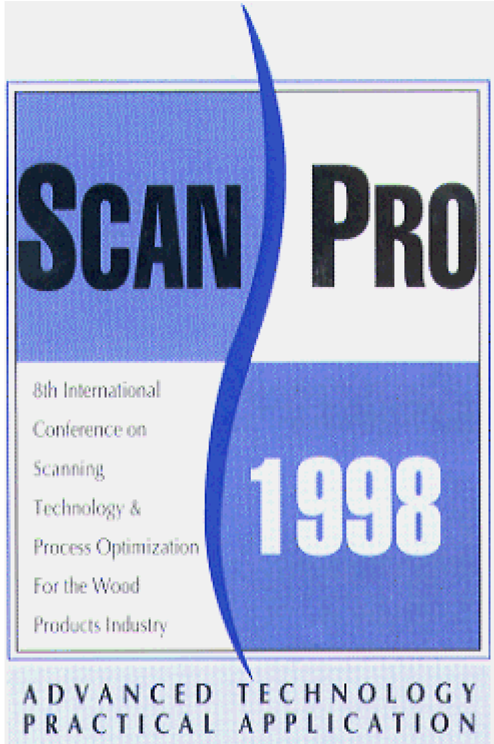

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